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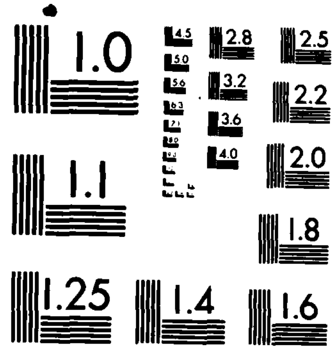

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A DIGITAL CAMERA SYSTEM FOR NON-INTRUSIVE MEASUREMENT OF EXPERIMENTAL RADAR TEST TARGET POSITION

by

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System requirements for the Compact Backscatter Measurement Range stipulate a ± 10 degree phase accuracy at 30 GHZ, or an equivalent ± 0.1 mm test target position accuracy. Accurate target position data are necessary to correct for position dependent phase shift during system calibration. A non-intrusive position measurement system has been implemented with a digital camera and installed in the compact range area. It has successfully produced data that can be computer processed to determine target position with the required accuracy.

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INTRODUCTION

Target position information is critical to the operation of the radar cross section (RCS) measurement range. Movement of a target during changes in aspect angle or antenna polarization will introduce a range dependent phase shift which must be corrected for during data calibration.

The hardware components of an accurate target position measurement system for the compact range have been completed and installed in the range area. The purpose of this report is to describe the details of the hardware utilized for this position measurement system. The system consists of a digital camera, its controller and hardware to move the camera in two dimensions, X and Y.

A software effort to process data that is produced by the camera is now underway. This software development will be described in a subsequent report.

CHAPTER I

SYSTEM OVERVIEW

Hardware for the target position measurement system includes a digital camera, its controller, hardware for translating the camera in the X and Y directions, a direct memory access (DMA) interface for transferring data produced by the camera to a DEC PDP 11/23 computer, and a monitor for viewing the camera image. A block diagram of the system is shown in Figure 1.1. The following is a brief description of how the system is used, which will help explain the various blocks shown in Figure 1.1.

The camera is installed in the ceiling and looks down on the target. The target can be brought into view by stepper motors on the camera mounting unit. Actual signals that move the stepper motors are produced by the stepper motor control unit. Two front panel momentary contact switches, one for X and the other for Y, control the direction the camera moves. Another front panel knob controls the speed of the stepper motors. Open collector logic in the stepper motor control unit permits either the front panel switches or the computer to drive the stepper motors. When the computer drives the stepper motors, control commands are issued to the measurement processor unit over an IEEE-488 interface (see Appendix A). The measurement processor then produces the

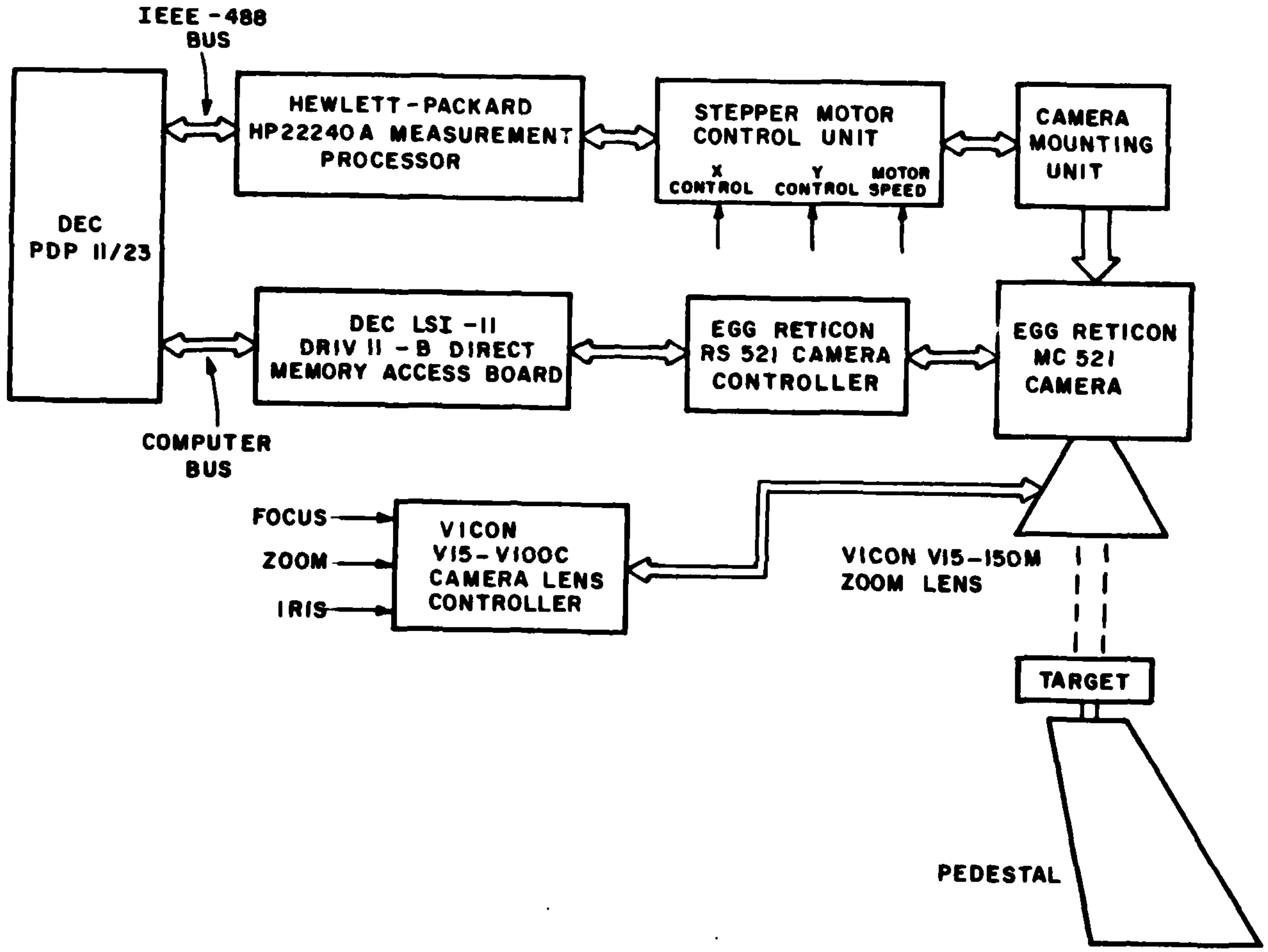


Figure 1.1. Block diagram of target position measurement system.

necessary signals needed for the stepper motor control unit to step the motors. Once the camera has been positioned so the target appears in the field of view, the lens zoom and focus unit can be used to refine the picture. At this point, the camera is ready to transfer data to the computer. The DMA interface in the computer is enabled to accept data from the camera controller. At the start of a new camera frame the camera controller digitizes the signal produced by the camera and transfers the data to the computer. When all camera data has been transferred to the computer the process is complete. The data can be processed using computer software to extract positioning information.

The following sections of the chapter contain detailed information on the various blocks of the position measurement system.

A. CAMERA AND CAMERA CONTROL UNIT

The camera is a 128 x 128 photo diode array (see Appendix A) which is sensitive to light intensity. A video signal that contains the analog voltage of each photo diode or pixel is produced by the camera. The controller controls various analog properties of the camera and also digitizes each pixel voltage. The digital or grey level value of each pixel ranges from 0 to 63 (6 bits).

The camera is free running. That is, it continuously presents camera frames to the controller. The frame rate of the camera can be adjusted from 15 to 300 frames/second. Due to transfer speed limitations of the DMA board, the camera can not run at its maximum

frame rate. The maximum frame rate is found by the following calculation. The maximum transfer rate of the DMA is 250,000 transfers/second, which is 4 μs per transfer. The camera controller produces 128 x 128 = 16,384 digital pixel values per frame. However, the controller, via SW2 switch 4 setting, presents two pixel values in each 16 bit word to the DMA board. This results in 8192 transfers needed for each frame. Therefore, the time to transfer one complete frame is 8192 transfers x 4 μs/transfer = 32.768 ms, or roughly 30 frames/second maximum frame rate.

B. CAMERA MOUNTING UNIT

The camera mounting unit is a simple mechanical device that attaches the camera to a platform that moves via two stepper motors, one for X direction and one for Y direction. The platform is situated on two perpendicular screw gears that are driven by the stepper motors. Twelve inches is the total travel distance in both directions. Each stepper motor is a 200 step per revolution motor and the screw gear takes five revolutions to move the platform one inch. Therefore, the distance per motor step is 5 revolutions/inch • 200 steps/revolution = 1000 steps/inch, or 0.001 inches/step.

Provisions have been made so that the stepper motor will not drive the platform into the stop at the ends of travel of either screw gear. Four micro switches, one for each end of the screw gears, control this function. The switches are positioned so that the platform depresses the switch before it hits the stop. When any of the micro switches is

depressed, a signal is sent back to the stepper motor control unit that inhibits any more motor steps into the switch even if the computer or front panel momentary contact switches on the stepper motor control unit are still trying to drive the motor. The motor can be stepped off of the switch by reversing direction.

C. STEPPER MOTOR CONTROL UNIT

The stepper motor control unit controls the stepper motors that move the camera. It has two front panel momentary contact switches, one each for X and Y, that determine motor direction. A front panel knob controls motor speed. From this information the correct four phase sequences for the stepper motors are generated. Two 14 bit counters for the X and Y directions record motor shaft position. One motor step corresponds to one count of the counter. Motor direction determines whether the counter counts up or down. This provides relative camera position on the camera mounting unit.

Open collector logic permits computer control of the stepper motors and access to the X and Y counter values. A direction and clock signal is necessary for each motor. One clock pulse steps the motor once. Another input signal controls a multiplexer that determines whether the X or Y counter is read. Lastly, both counters can be cleared by a sixth computer signal.

D. MEASUREMENT PROCESSOR

Computer control of the camera stepper motors is achieved by the measurement processor, which is an IEEE-488 device that interfaces the DEC PDP 11/23 computer to the stepper motor control unit. A digital input and digital output board are installed in the measurement processor. The digital output board delivers six signals to the stepper motor control unit for motor control; a direction and clock signal for each motor, a multiplexer input that chooses which stepper motor shaft counter to be read, and a clear input that clears both shaft counters. The digital input board receives sixteen input bits that carry the shaft counter data relating camera position. Commands inherent to the measurement processor allow setting and toggling the logic level of the six control lines and reading of the shaft counter data.

E. DMA INTERFACE

Digitized pixel data from the camera controller is transferred to the computer through a DMA interface because the data rate is too fast for processor controlled digital input operations. Two pixel valves are transferred in one 16 bit DMA cycle. Therefore, the number of DMA cycles equals one half number of pixels, or 8192 DMA cycles. Each pixel occupies one byte in the computer memory. The interface is a standard DEC LSI-11 DMA board (see Appendix A) with appropriate cabling to the camera controller.

F. VIDEO MONITOR

The video monitor displays the image the camera is viewing. It is directly connected to the camera control unit through standard X-Y-Z connections (X and Y are scan signals and Z carries the analog pixel valves).

G. CAMERA LENS AND LENS CONTROLLER

The camera has a lens that can be remotely focused, zoomed and iris controlled. It zooms from 15mm to 150mm. Its control unit has six front panel push buttons, two for each of the controlled functions. Focus can be adjusted for near and far, one button for each. Camera field of view can be zoomed in and out (again one button for each). Light intensity into the camera is controlled by the iris, which can be opened and closed with two buttons.

CHAPTER II

TECHNICAL INFORMATION

This chapter covers technical information, including discussions, schematics, wiring lists, etc., on the various blocks of the target positioning system.

A. CAMERA MOUNTING UNIT

Found in Figure 2.1 is a pictorial view of the camera mounting unit. Cable 1 carries the stepper motor phases from the stepper motor control unit, micro switch signals are returned through cable 2 to the stepper motor unit and cable 3 carries the camera analog signals to the camera controller. All grounds of the micro switches are wired together and each normally open (NO) and normally closed (NC) contact is brought out to the cable 2 connector. Wiring lists for cables 1 and 2 are in Tables 2.1 and 2.2. respectively.

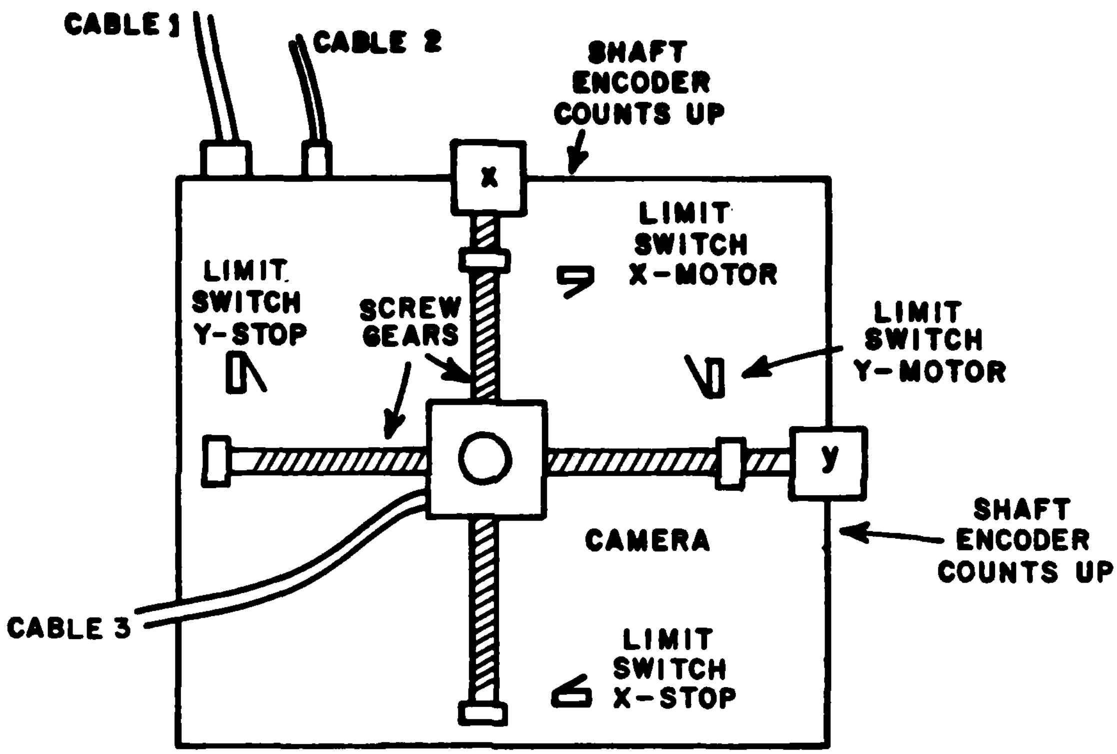


Figure 2.1. Top view of camera mounting unit.

TABLE 2.1

CABLE 1 - STEPPER MOTOR PHASE CABLE CONNECTOR WIRING LIST

Pin Letter	Signal	Connector Wire Color	Cable Wire Color
A	Y ϕ_1	Green	Black-green
B	Ground	Shields-ground	Shields
C	X ϕ_4	Red/white	White
D	X ϕ_1	Green	Black-white
E	X ϕ_2	Red	Brown
F	Y - resistor	White	Black-brown
G	not used	---	---
H	Y ϕ_2	Red	Yellow
J	Y ϕ_4	Red/white	Blue
K	Y ϕ_3	Green/white	Green
L	X - resistor	White	Black-blue
M	X ϕ_3	Green/white	Red
N	Y - resistor	Black	Black-Red
P	X - resistor	Black	Black-yellow

TABLE 2.2

CABLE 2 - MICRO SWITCH CABLE CONNECTOR WIRING LIST

Pin Letter	Signal	Connector Wire Color	Cable Wire Color
A	X MOTOR - NO	Green	White
B	X MOTOR - NC	Red	Green
C	X STOP - NC	Purple	Red
D	X STOP - NO	Yellow	Black
E	Y STOP - NO	Yellow	Black
F	Y STOP - NC	Purple	Red
H	Y MOTOR - NC	Red	Green
J	Y MOTOR - NO	Green	White
K	GROUND	Black	Shield

B. STEPPER MOTOR CONTROL UNIT

The six circuit blocks of the stepper motor control unit are shown in Figure 2.2, followed by the circuit schematics in Figures 2.3 to 2.8. Figure 2.9 relates integrated circuit package letter-number identification to circuit board location. Table 2.3 lists computer input lines, their logical states and associated action.

C. MEASUREMENT PROCESSOR

A standard DEC IEEE-488 cable interfaces the measurement processor to the computer. The digital input and digital output cards inside the measurement processor occupy slots 3 and 4, respectively (counting from the bottom slot up). Two cables carrying the six stepper motor control signals and sixteen bits of shaft encoder data connect the measurement processor and stepper motor unit. Each cable has a special connector that mates to the measurement processor, one cable for each of the digital I/O boards. At the stepper motor unit, both cables are wired into a single DB-25 connector. A wiring list for the cables is shown in Table 2.4.

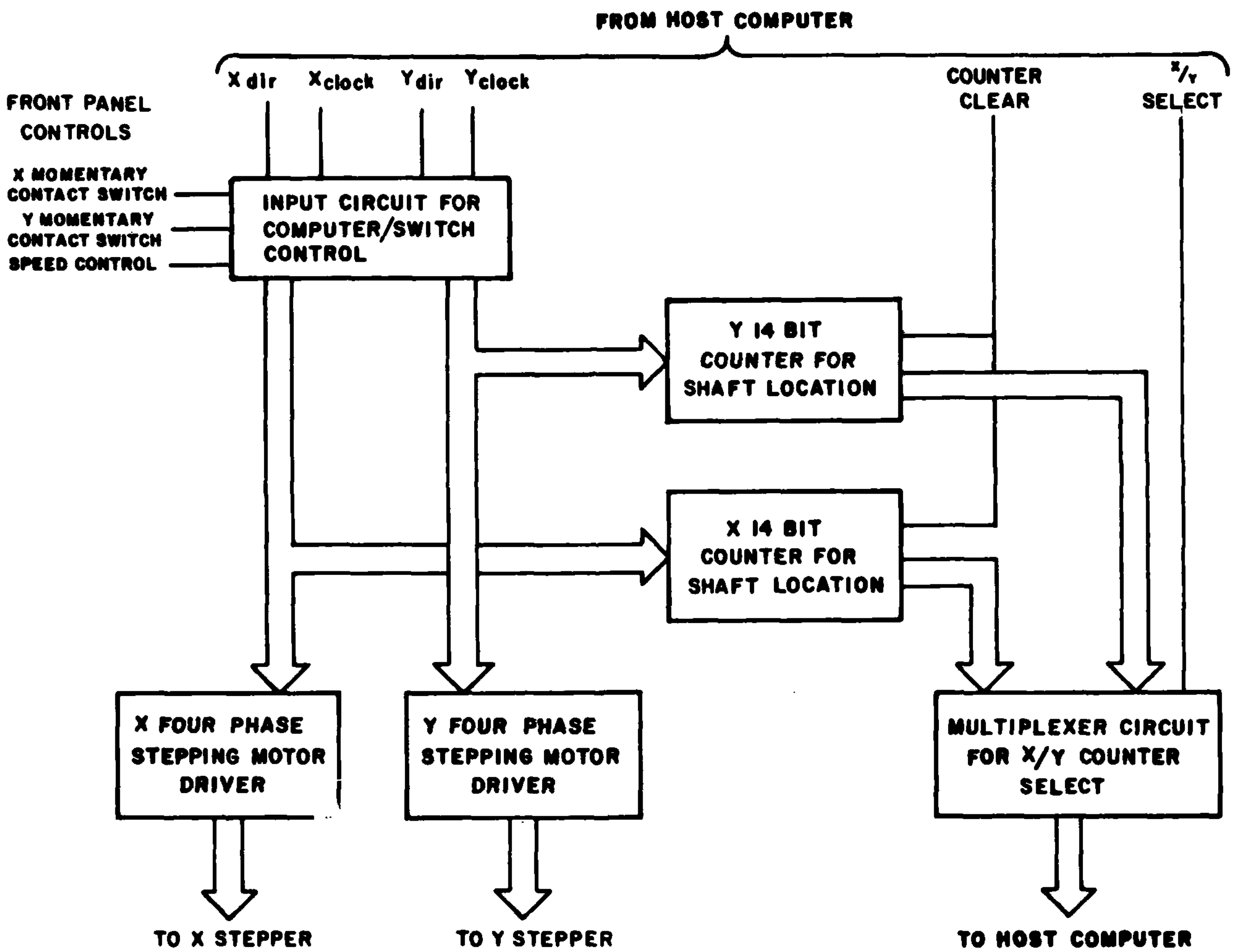


Figure 2.2. Stepper motor control unit circuit block diagram.

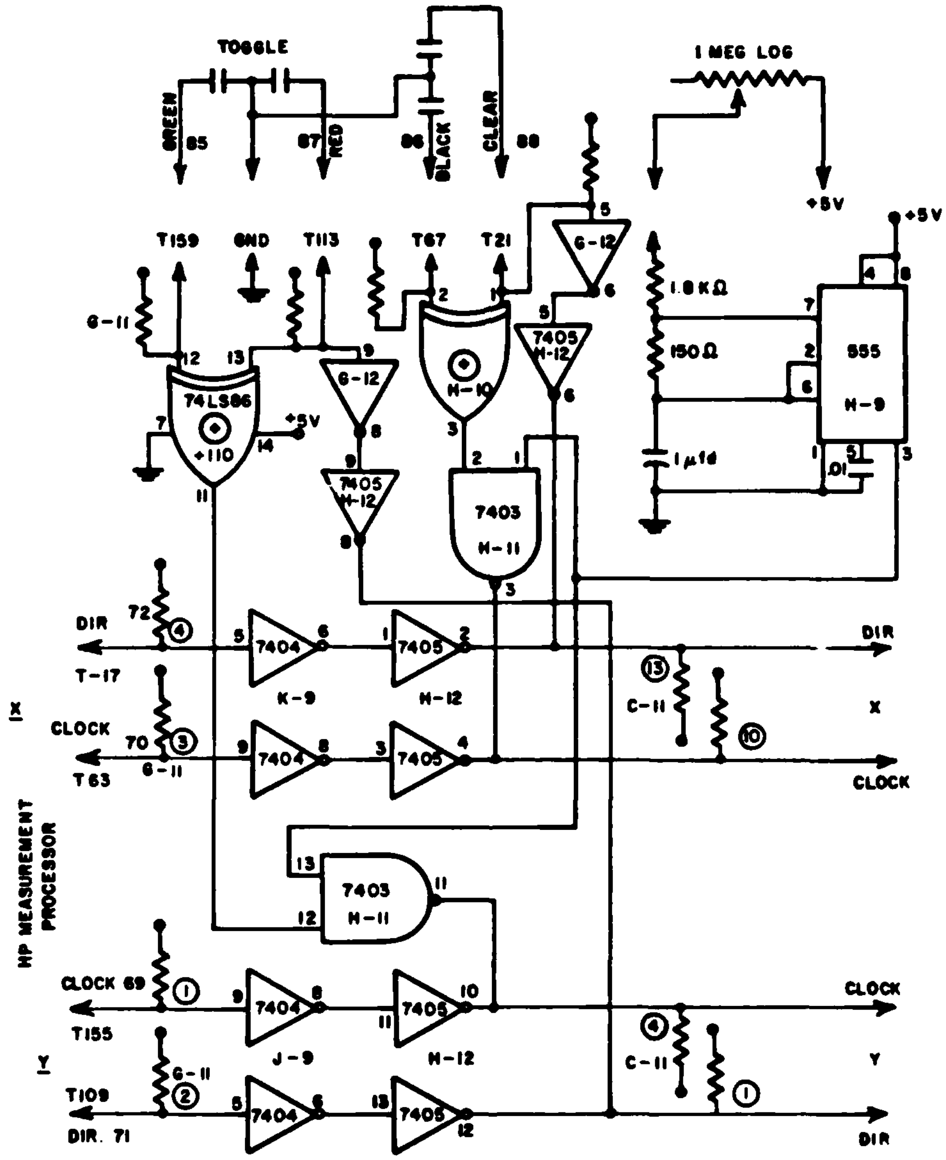


Figure 2.3. Input circuit schematic for switch or computer control.

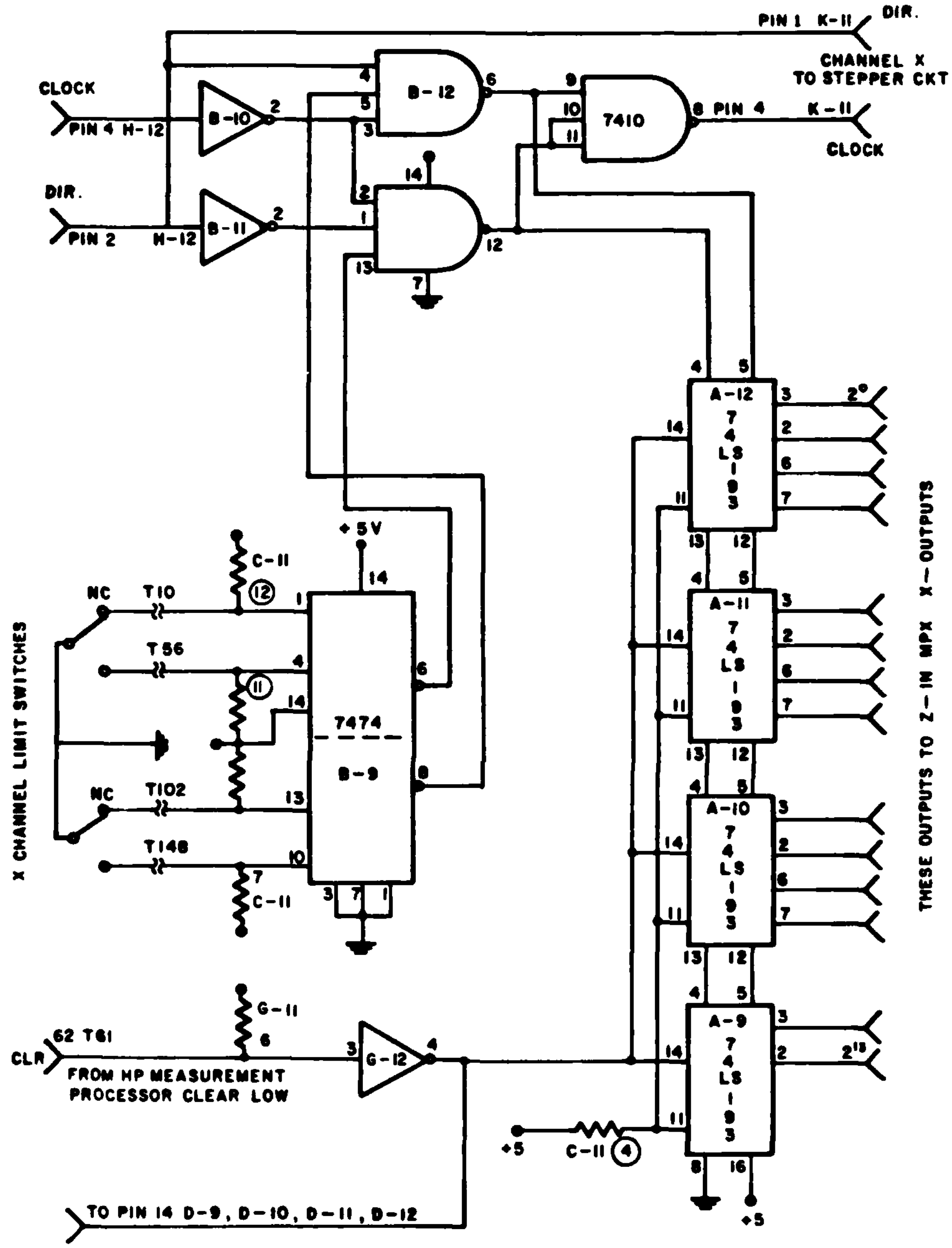
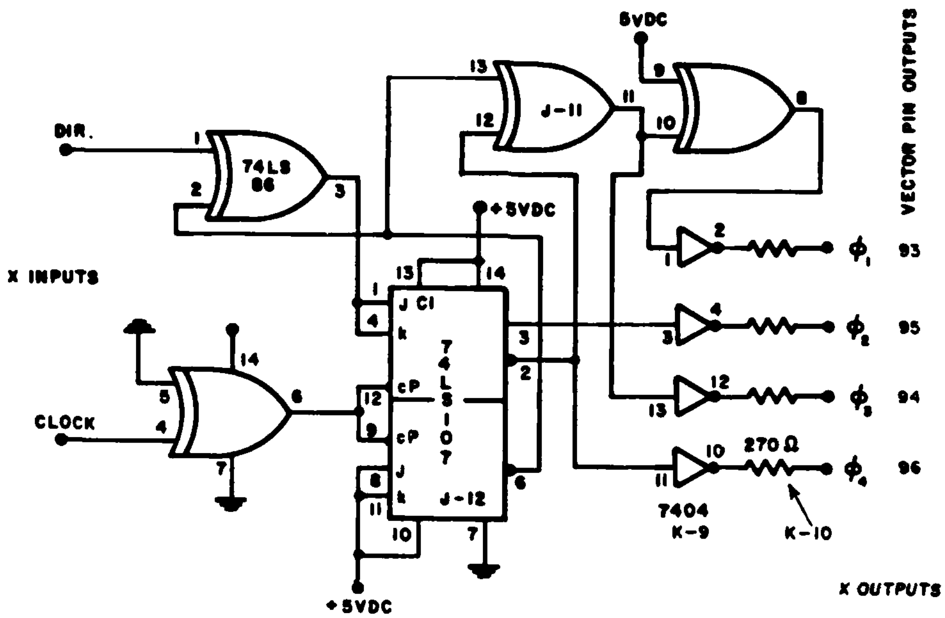


Figure 2.4. 14 bit x shaft counter schematic.



OUTPUTS

	X		Y	
ϕ_1	T 161	93	T 160	89
ϕ_2	T 115	95	T 114	91
ϕ_3	T 69	94	T 68	90
ϕ_4	T 23	96	T 22	92

Figure 2.5. X direction four phase stepper motor driver circuit.

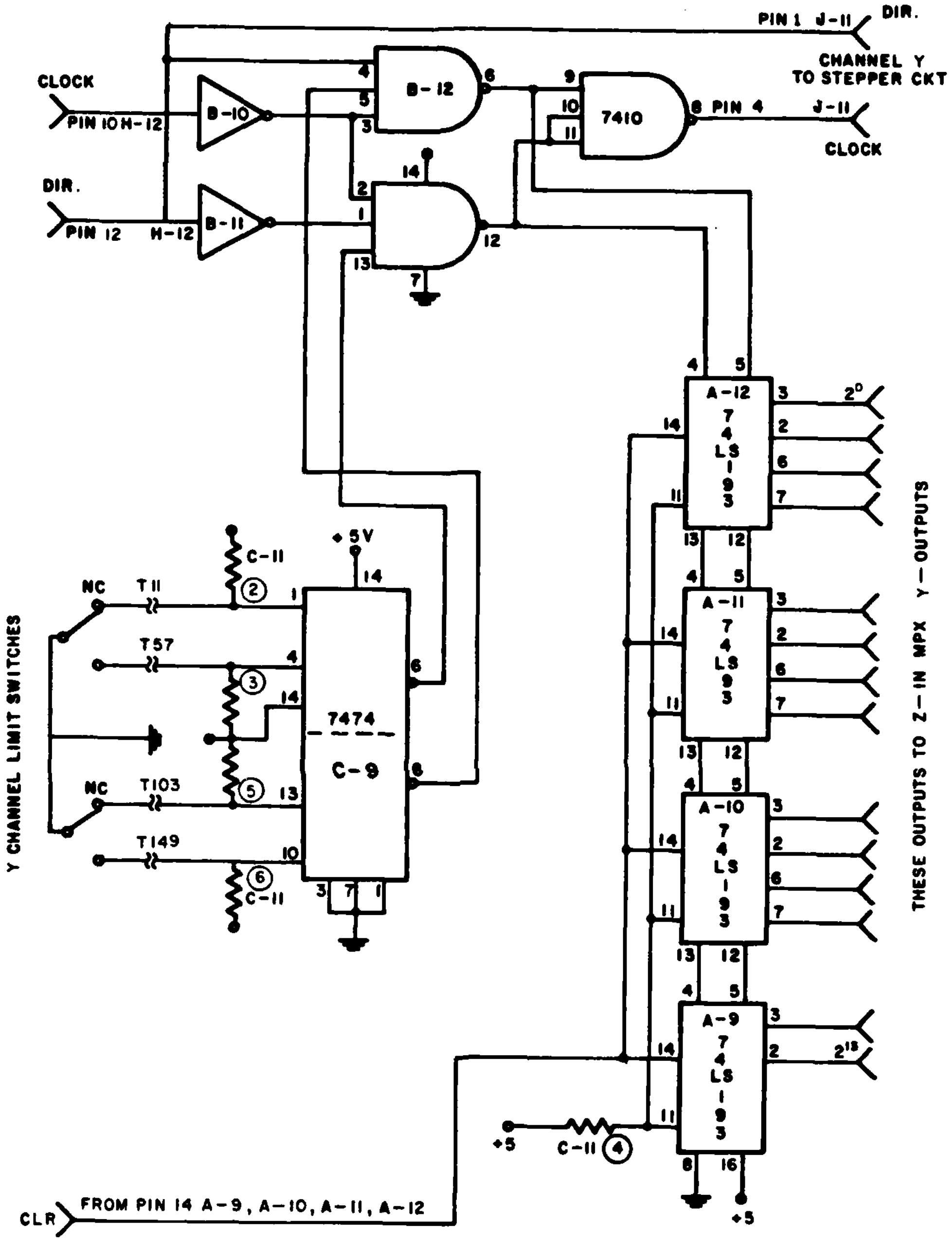
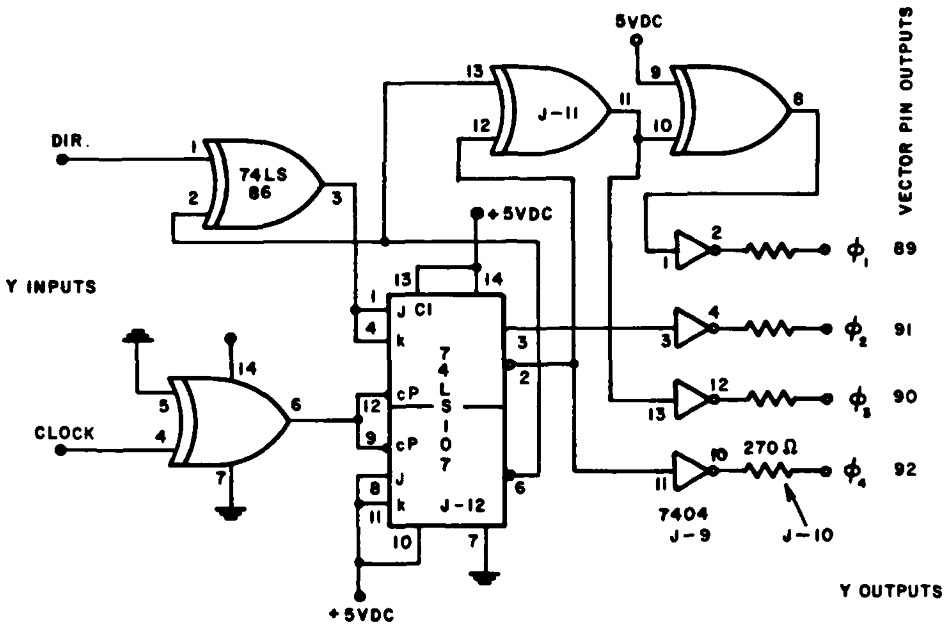


Figure 2.6. 14 bit Y shaft counter schematic.



OUTPUTS

	X		Y	
ϕ_1	T 161	93	T 160	89
ϕ_2	T 115	95	T 114	91
ϕ_3	T 69	94	T 68	90
ϕ_4	T 23	96	T 22	92

Figure 2.7. Direction four phase stepper motor driver circuit.

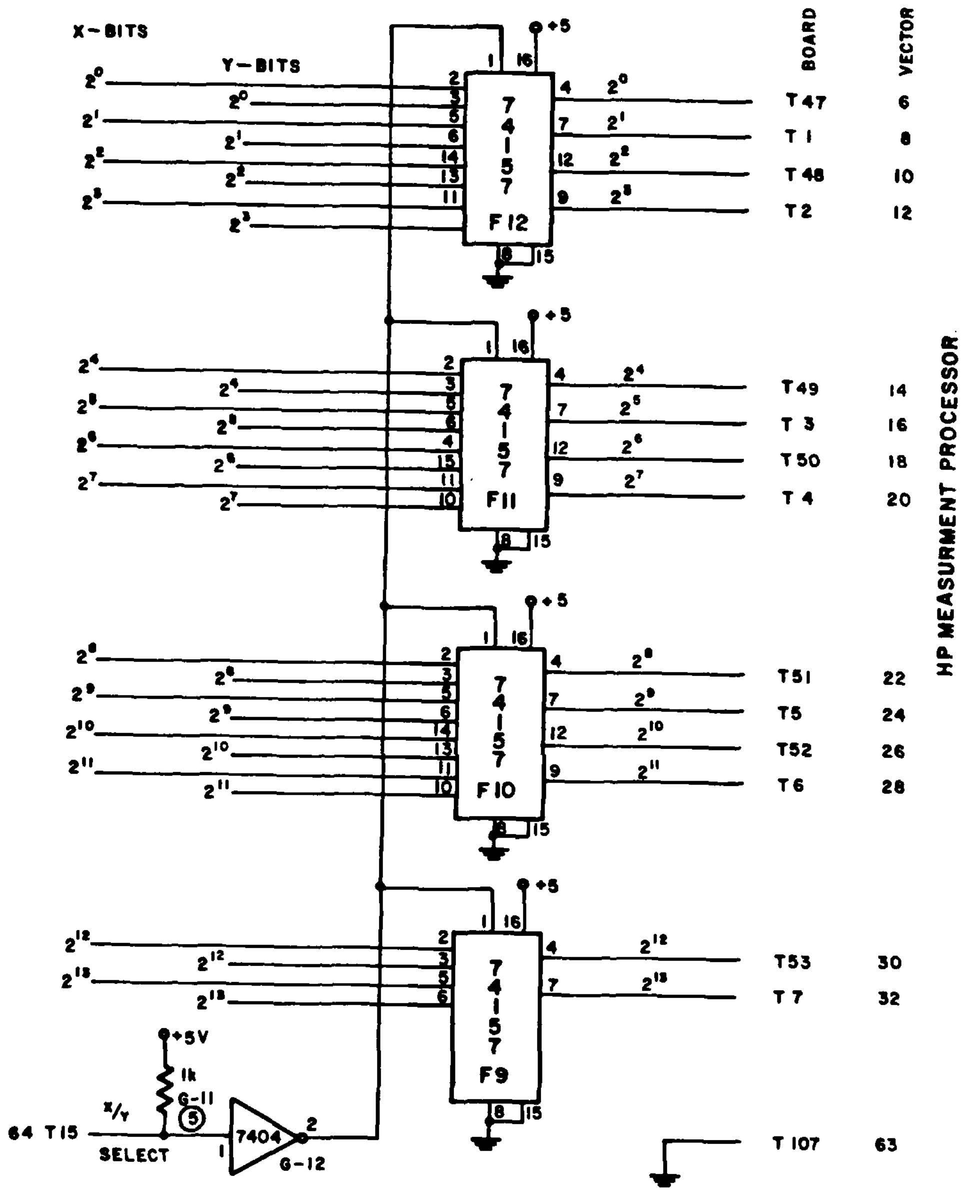


Figure 2.8. Multiplexer circuit for reading X or Y shaft counter.

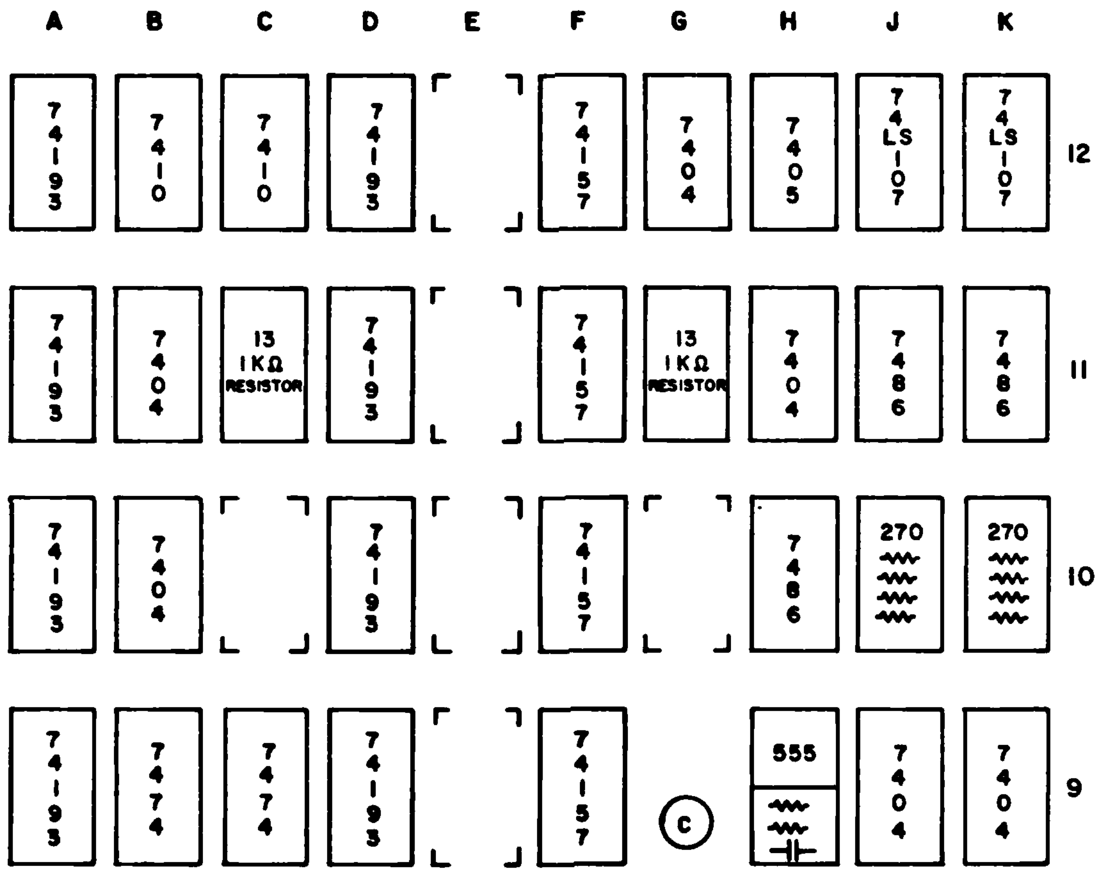


Figure 2.9. Stepper motor control unit board layout.

TABLE 2.3

COMPUTER INPUT LOGIC STATES AND ASSOCIATED ACTIONS

Signal	State	Action
X Clock	1 Pulse	1 Motor step
X Direction	High Low	Counter counts up Counter counts down
Y Clock	1 Pulse	1 Motor step
Y Direction	High Low	Counter counts up Counter counts down
X/Y Select	High Low	X Counter selected Y Counter selected
Counter clear	Low	Counters cleared

TABLE 2.4

WIRING LIST FOR CABLE CONNECTING MEASUREMENT PROCESSOR
AND STEPPER MOTOR CONTROL UNIT

Measurement Processor Output Lines - 'Connector 4-2

Signal	Digital Ouput Channel	Measurement Processor Connector Pin	Cable Wire Color	Stepper Motor Control Unit DB-25 Connector Pin
X/Y shaft counter select	17	40	Grey	18
X/Y shaft counter clear	18	39	White/violet	19
X direction	19	38	Violet	20
X clock	20	37	White/blue	21
Y direction	21	36	Blue	22
Y clock	22	35	White/green	23

TABLE 2.4 (CONTINUED)

Measurement Processor Input Lines - Connector 3-2

Signal	Digital Ouput Channel	Measurement Processor Connector Pin	Cable Wire Color	Stepper Motor Control Unit DB-25 Connector Pin
(shaft counter bit)				
0	17	40	Grey	1
1	18	39	White/violet	2
2	19	38	Violet	3
3	20	37	White/blue	4
4	21	36	Blue	5
5	22	35	White/green	6
6	23	34	Green	7
7	24	33	White/yellow	8
8	25	32	Yellow	9
9	26	31	White/orange	10
10	27	30	Orange	11
11	28	29	White/red	12
12	29	28	Red	13
13	30	27	White/brown	14
14	31	26	Brown	15
15	32	25	White/black	16
Ground	--	24	White	17

D. DMA INTERFACE

Digital pixel data is transferred from the camera controller to the POP 11/23 memory through a standard DEC DMA board (see Appendix A). The following discussion in this section assumes the reader is familiar with the DMA board and camera controller. Consult the reference manuals listed in Appendix A for information on these devices.

Full word, DMA board to memory transfers (DATO) are performed. The camera controller must set up the following DMA control signals before a transfer: Word count increment enable (WC INC ENB), bus address increment enable (BA INC ENB), C1, CO, A00, and ATTN. CYCLE REQUEST is then asserted and input data in the data buffer register is latched. At this time, the DMA board requests control of the computer bus and, when granted, transfers the data from the data buffer resister to memory. When complete, the DMA board relenqueshes control of the bus back to the processor and the DMA is idle until the next transfer is initiated by asserting CYCLE REQUEST again. Before the camera controller can initiate the first transfer, a program must be executed that sets up the DMA board WORD COUNT REGISTER, BUS ADDRESS REGISTER, and CONTROL/STATUS REGISTER. The program then waits for a signal to be asserted from the camera controller indicating the end of the present frame (this status signal is wire to input bit STATUS A of the DMA CONTROL/STATUS REGISTER). When STATUS A is asserted, the program enables DMA operation by setting the GO bit in the CONTROL/STATUS REGISTER. Any CYCLE REQUEST after this point will generate a DMA transfer. The number of transfers

desired is loaded into the WORD COUNT REGISTER before the DMA board is enabled. For our application, one complete camera frame is transferred, which is 8192 transfers at two pixels per transfer. When the frame transfer is complete, the DMA operation is halted and the data in memory can be processed.

Two 40 pin connectors on the DMA board, labelled Input Connector (J2) and Output Connector (J1), are provided for interfacing to the camera controller. All but three of the interface connections are made to the input connector (J2). So, rather than use another 40 conductor cable to interface only these three signals to the output connector (J1), modifications were made to jumper the three signal pins on the output connector to three unused pins on the input connector. The three jumpered signals and their new pins on the input connector (J2) are:

1) CYCLE REQUEST - Pin W,
2) WC INC ENB - Pin X, and
3) STATUS A - Pin BB.

On the camera controller side, two back-panel connectors marked A/D and DATA A, carry the necessary control and data signals. Two eight bit pixel valves are presented to the A/D connector with a data ready flag (-DATA READY) indicating valid data. -DATA READY is wired to CYCLE REQUEST of the DMA board to initiate transfers. The only other control signal used on the A/D connector is -STATUS, which is high during a camera frame and low during frame retrace. This signal is wired to STATUS A of the DMA board and is used to indicate the end of a camera frame. The DATA A connector carries various signals but +5 volts and

ground are all that is used. DMA control signals WC INC ENB, BA INC ENB, and A00 are tied to +5 volts because only word transfers are performed. The type of data transfer is chosen by the logic levels applied to the C0 and C1 DMA control signals. For DATO transfers, C0 and C1 are tied to ground and +5 volts respectively. The last DMA control line, ATTN, is also tied to ground.

One slight modification was done to the -DATA READY signal. It is wired to CYCLE REQUEST, which requires a 1 μs minimum pulse, whereas -DATA READY is only 100 μs in duration. A one-shot was added to lengthen the -DATA READY pulse to 1.5 μs. A schematic of the circuit is shown in Figure 2.10.

The DMA board and camera controller have different types of cable connectors. So, a splice box was added to wire the different cable connectors together. The one-shot circuit is also housed in this box. Figure 2.11 pictorially lays out the cable connection scheme. Tables 2.5 to 2.9 give wiring lists.

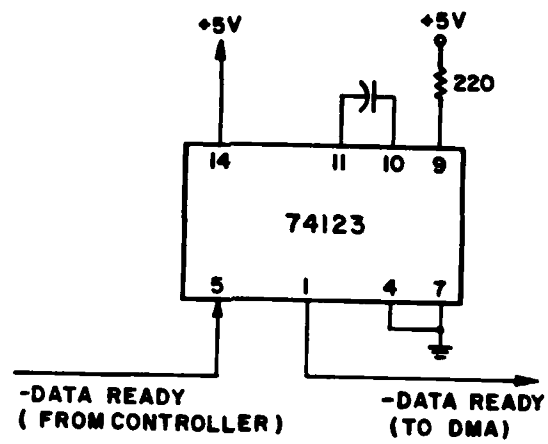


Figure 2.10. Schematic of one-shot circuit to lengthen -DATA READY pulse.

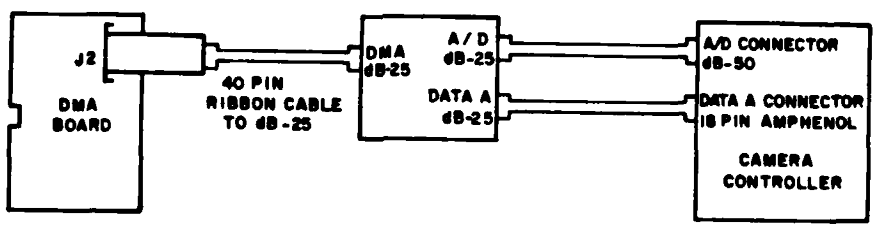


Figure 2.11. Block diagram illustrating cable connections between DMA board and camera controller.

TABLE 2.5

WIRING LIST FOR DMA 40 PIN RIBBON CABLE TO DMA DB-25

40 Pin DMA Input Connector(J2)	DMA Signal	DMA DB-25	Camera Controller Signal
SS	bit 1	1	+ 2 odd
UU	bit 0	2	+ 1 odd
FF	bit 9	3	+ 2 even
BB	STATUS A	4	-status
W	CYCLE REQUEST	7	-data ready
PP	bit 2	9	+ 4 odd
JJ	bit 10	10	+ 4 even
MM	bit 3	11	+ 8 odd
LL	bit 11	12	+ 8 even
X	WC INC ENB	22	+ 5 Volts
DD	bit 8	16	+ 1 even
NN	bit 12	17	+16 even
RR	bit 13	18	+32 even
HH	bit 5	19	+32 odd
KK	bit 4	20	+16 odd
F	A00	22	+ 5 Volts
T	C1	22	+ 5 Volts
J	BA INC ENB	22	+ 5 Volts

TABLE 2.5 (CONTINUED)

40 Pin DMA Input Connector(J2)	DMA Signal	DMA DB-25	Camera Controller Signal
D	ATTN	24	ground
N	CO	24	ground
CC	bit 7	24	ground
EE	bit 6	24	ground
TT	bit 14	24	ground
VV	bit 15	24	ground
A	ground	24	ground

TABLE 2.6

WIRING LIST FOR A/D DB-25 TO DMA DB-25

A/D DB-25	Signal	DMA DB-25
1	+32 odd	19
2	+16 odd	20
3	+ 8 odd	11
4	+ 4 odd	9
5	+ 2 odd	1
6	+ 1 odd	2
7	-data ready to one-shot pin 5	7 from one-shot pin 1
9	-status	4
12	+32 even	18
13	+16 even	17
14	+ 8 even	12
15	+ 4 even	10
16	+ 2 even	3
17	+ 1 even	16
25	ground	24

TABLE 2.7

WIRING LIST FOR A/D DB-50 TO A/D DB-25

A/D DB-50	Signal	A/D DB-25
5	+32 odd	1
7	+16 odd	2
9	+ 8 odd	3
11	+ 4 odd	4
13	+ 2 odd	5
15	+ 1 odd	6
29	-data ready	7
31	-status	9
38	+32 even	12
40	+16 even	13
42	+ 8 even	14
44	+ 4 even	15
46	+ 2 even	16
48	+ 1 even	17
17	ground	25

TABLE 2.8

WIRING LIST FOR DATA A DB-25 TO DMA DB-25

Data A DB-25	Signal	DMA DB-25
1	ground	24
2	+5 Volts	22

TABLE 2.9

WIRING LIST FOR DATA 18 PIN AMPHENOL TO DATA A DB-25

Data A 18 Pin Amphenol	Signal	Data A DB-25
A	Ground	1
B	+ 5 Volts	2

APPENDIX A

EQUIPMENT AND REFERENCE MANUALS

Following is a list of vendor equipment, model numbers and reference manuals.

Equipment	Company	Model Number	Reference Manuals
Camera and Controller	Egg Reticon	Camera: MC521 Controller: RS521	•Operation and Maintenance Manual, MC521/RS521, Camera/Controller System •RSB 5206/5208, Operation and Maintenance Manual 045-0078 •MCS528 Addendum Package
DMA Board	DEC	DRV11-B	•Digital Microcomputer Interfaces Handbook •DRV11-B General Purpose DMA Interface User's Manual
Measurement Processor	Hewlett-Packard	HP2240A	•HP2240A Measurement and Control Processor User's Manual •HP2240A Measurement and Control Processor and Accessories Installation and Service Manual
Camera Mounting Unit	Made by Art Eberle		•none
Stepper Motors	Superior Electric	M061-FC08C2	•none
Camera Lens	Vicon Ind, Inc.	V15-150M	•Vicon reference notes x 103 - 383
Camera Lens Controller	Vicon Ind, Inc.	V15-V100C	•Vicon reference notes x 104 - 1182

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